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STUDY ON EFFECT OF HYBRID FRP LAMINATES WRAPPED EXTERNALLY (U-WRAP) ON REINFORCED CONCRETE BEAMS

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ABSTRACT

Recently fibre reinforced polymer composite material namely glass FRP, carbon FRP, basalt FRP etc, is being used as strengthening material. Each technique has its own merits and limitations. Experimental study have been conducted on Reinforced concrete beams which are externally strengthened with GFRP and CFRP as double layer one above the other and it is referred as Hybrid FRP techniques is attained with epoxy resin as adhesive compound. All the ingredients in the beam specimens were maintained with same consistency. A total six beams were cast for the experimental investigation. Out of that three were kept as control specimens and the remaining three were strengthened with double layer of CFRP and GFRP in the U-Wrap pattern. From the overall experimental investigation it can be observed that there is an appreciable increase in ultimate load carrying capacity of the beams strengthened with hybrid FRP laminates.

Key words: Reinforced concrete beam, Hybrid FRP laminates, External strengthening, Epoxy resin

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1. INTRODUCTION

Strengthening of structural elements are one of the most challenging task in Civil Engineering application, since strength enhancement can be done without increase in the cross sectional dimension of the structural element. This is proven to be achieved by strengthening the reinforced concrete elements externally by using FRP wraps. For strengthening of RC elements

FRP composite material have emerged as a cost-effective alternative to conventional materials. FRP composite is made of mixed polymer matrix like reinforcement further manufactured in the form of a woven mat.

Generally fibre composites matrix can be mainly divided in to two categories based on the length parameter of the fibre, fibre composites with longer length are classified as continuous fibres and fibres with shorter lengths are classified as discontinuous fibres.

Two or three varieties of fibres together used in a single matrix is referred to as Hybrid FRP composites in general [3], there is an increase in Young's modulus of solids and foams by 78% and 113%, respectively. The density percentage of CFRP also increased around 10% to 30%. The behaviour of the cellular structure have shown results in the increase of Modulus of Elasticity for FRPs by 35% when carbon fiber/polypropylene (CF/PP) was used to make wraps prepared by microcellular injection molding [4].

1.1. Review of Literatures

For the past around twenty years the FRP composite materials have been used as an alternate material which is conventionally used in many fields such as Aerospace, Automobile, Civil Engineering, Sports etc, which has proved more advantages in enhancement of the structural and mechanical behaviour of FRP composites Nobe. R et al. (2019).

Glass fibre reinforced polymer (GFRP) are most commonly used composite matrix which offer good mechanical properties such as strength, stiffness, resistance against thermal expansion, resistance against any impact force, any hazard chemical, friction and further more durable which is conveniently used with less workmanship on regular tools (Prakash, S, 2019). Toutanji et al. (1997) has noticed that the flexural behaviour of strengthened beam proven to be better than the control beams and the strengthened beams show an increase in ultimate load carrying capacity.

Manickam et al. (2018) stated that the buckling stability of the material increases with the increase in the number of layers of wrap sheets of different FRPs.

1.2. Aim and Objective

The main objective of this investigation is to study the effectiveness of Hybrid FRP laminates as strengthening material on flexural behavior of reinforced concrete beams.

The objectives can be achieved by conducting the following tasks:

- Evaluation of mechanical properties of concrete.
- Testing of control Reinforced Concrete beams.
- Testing of reinforced concrete beams strengthened with U-Wrap pattern using hybrid fibre reinforced polymer (Carbon & Glass FRP) laminates.

1.3. Strengthening of Beams

For strengthening the beams using the FRP laminates, before wrapping the sheets externally on the RC beams, the required region of concrete surface was made rough using a coarse sand paper texture and cleaned with an air blower to remove all dirt and debris. Once the surface is prepared to the required standard the epoxy resin (PartA&PartB) is mixed in such a proportion that prescribed by the manufacturer. After application of the resin uniformly over the surface to a thickness not exceeding 3mm, the first layer (GFRP) composite fabric is placed with more care. After allowing the wrap to get dry for 24 hrs the epoxy resin is applied over the fabric and CFRP sheet is placed. This operation is to be carried out at room temperature. Concrete beams wrapped with hybrid fabric (GFRP&CFRP) are allowed to get dried for 24 hours at room temperature before testing.

2. EXPERIMENTAL INVESTIGATION

Experimental investigation involves with the characterisation of the ingredient materials for casting of concrete cube, cylinders and reinforced concrete beams specimens.

2.1. Concrete Making Materials

Locally available concrete making materials such as cement, Fine aggregate (FA) and Coarse aggregate (CA) are collected and tested for its basic properties and the test results are tabulated below.

Table 1 Properties of Cement

Sl.No.	Name of Test	Results
1	Grade	53 Grade
2	Fineness	7.7%
3	Standard Consistency	33%
4	Initial Setting time	38 minutes
5	Specific gravity	3.12

Table 2 Properties of Aggregates

Sl.No	Name of Test	FA	CA
1	Specific Gravity	2.74	2.68
2	Water Absorption	1.20%	1.85%
3	Sieve Analysis	Zone II	Zone II
4	Fineness Modulus	2.9	6.5

2.2. Concrete Mix Proportioning

Mix proportioning for M30 grade concrete is arrived based on the codal provision of IS 10262:2009 and the details are tabulated below.

Table 2 Concrete Mix Proportion

Description	Water	Cement	FA	CA
Quantity (kg/m^3)	186	413	666	1138
Ratio	0.45	1	1.61	2.755

2.3. RC Beam Design

RC beam is designed following limit state method of design and an under reinforced section is preferred with a section size of 100mm width, 200mm depth and 1500mm length. The reinforcement detail of the beam is depicted below.

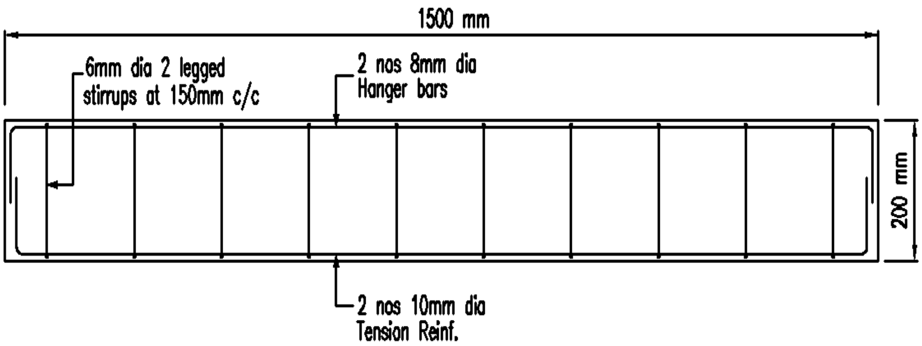

Figure 1 Reinforcement Details of Beam

2.4. Casting of Concrete and Reinforced Concrete Specimen

Casting of concrete and reinforced concrete specimens is carried out after arriving at a mix proportion by lots of trial mixes. Concrete specimens such as cubes and cylinders are cast & cured for 28 days. Six reinforced concrete beams have been cast in total; out of that three beams were normal control beams and the remaining three beams were strengthened with FRP.

Figure 2 Reinforcements placed inside the mould

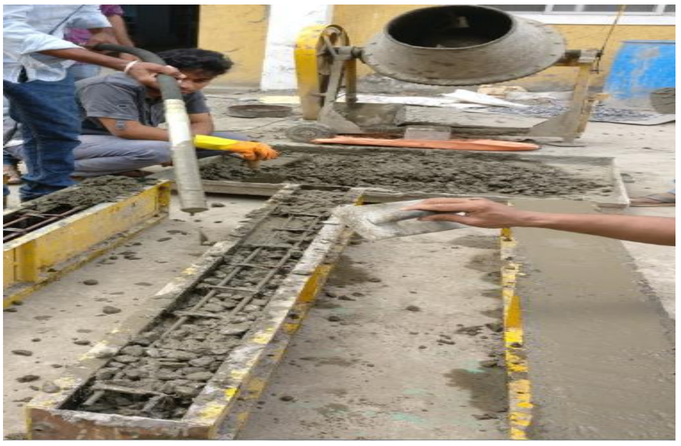

Figure 3 Casting of RC Beam Specimens

2.5. Strength Enhancement the RC Beam

The main objective of this experimental investigation is to enhance the strength of the beams using Hybrid fibre polymer laminates (GFRP & CFRP) wrapped one above the other as double layer in the U-Wrap pattern. The main advantage of the U-Wrap pattern is that the beams can withstand both flexural and shear deficiency. To achieve this one layer of CFRP laminate has been wrapped over a layer of GFRP laminate at three sides of the beam as U pattern throughout its length.

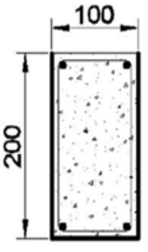

Figure 4 U-Wrap of RC Beam (GFRP & CFRP)

2.6. Process of Wrapping GFRP and CFRP

Surface preparation is carried out by just cleaning the surface after making the surface rough so as to accept the epoxy resin. Once the surface has been prepared to the required standard. The epoxy resin was applied to a maximum thickness of 3mm evenly on the surface. The first layer of GFRP laminate was placed on the epoxy resin with much care further the beams wrapped were left for 24 hours at room temperature. After the first layer is firmly set and dry, the second layer of the composite is laid over the epoxy resin applied and the beams left for 24 hours before testing.

Figure 5 Wrapping with Hybrid FRP (GFRP & CFRP) U-Wrap Pattern

2.7. Experimental Test Setup

All the specimens were tested under simply supported conditions in the load frame. The beams were tested under four point bending over a span of 1200 mm. The loading is transmitted through a load cell. The load was measured using an electrical load cell. Each beam was instrumented with linearly varying displacement transducer (LVDT) for measuring deflection at mid of span. All the beam specimens were placed in the loading frame test setup in such a way that the beam specimen is aligned to match with the line of support conditions as shown in the figure below.

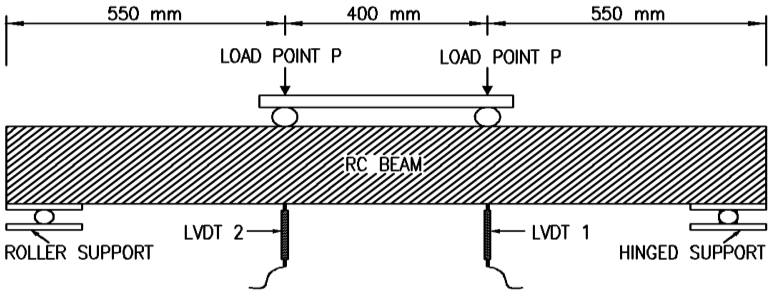

Figure 6 Experimental test setup

3. TESTING OF CONCRETE SPECIMENS

The concrete and reinforced concrete beams were cast as per the design mix and during each mix of concrete for casting the beam specimens, cubes and cylinders also cast. After 28 days of curing the cubes and cylinders were tested for its strength behaviour. The test results are tabulated below and the details of testing are depicted below.

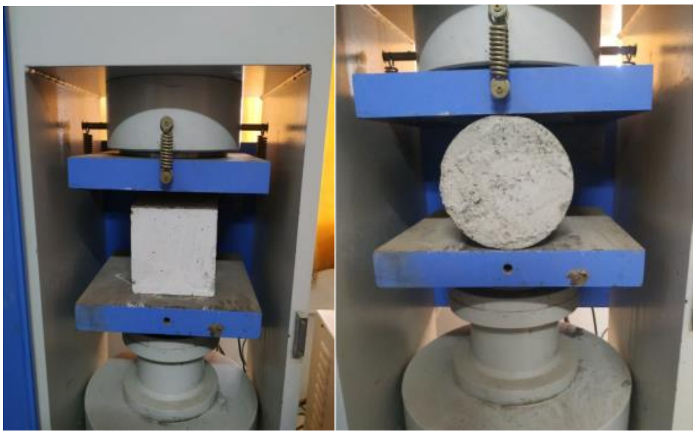

Figure 7 Testing of Concrete Specimens

Table 3 Test Results of Concrete Specimens

Test Results after 28 days	
Cube compressive strength	37.6 N/mm^2
Cylinder split tensile strength	3.4 N/mm^2

3.1. Testing of Control beams

Three beams were tested till failure in four point bending under load control on a reaction frame with a maximum load capacity of 200kN to know the average ultimate load of the concrete beams cast, and so as to compare with the strengthened beams. The test results in the form of Load with its corresponding deflection with graph is given below, further the details of testing are depicted below.

Figure 8 Testing of Control Beam

Table 4 Load –Deflection of Control Beam

Load (kN)	Control Beam (Flexure)		
	Lvdt1 (mm)	Lvdt2 (mm)	Lvdt3 Near center (mm)
0	0	0	0
5	0.225	0.350	0.510
10	0.495	0.610	0.690
15	0.780	0.850	1.000
20	1.176	1.180	2.100
25	1.512	1.700	2.600
30	1.878	2.200	3.100
35	2.354	2.550	3.500
40	2.800	2.900	3.900
45	3.360	3.500	4.000
50	3.925	3.850	4.520
55	4.478	4.300	5.010
60	5.055	4.850	5.400
65	5.235	5.265	5.630
70	5.435	5.512	5.910
75	5.795	5.900	6.200
80	5.912	6.100	6.800
82	6.240	6.320	7.400

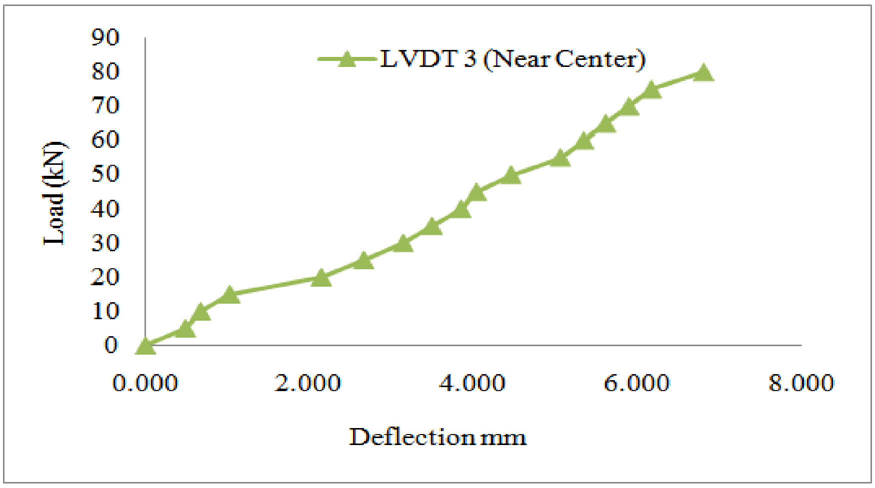

Figure 9 Approximate average load versus, Deflection - Control Beam (Flexure)

3.2. Testing of the Strengthened beams

The three strengthened beams using hybrid fibre laminates, ie. one layer of GFRP and one layer of CFRP laminates at three sides of the beams as U pattern throughout their length were tested by using the load frame test set up and the test results of one trial is tabulated below. The testing of strengthened beam is also depicted below.

Table 4 Load–Deflection of Strengthened Beam

Load (kN)	Deflection (mm)		
	Lvdt1	Lvdt2	Lvdt3 Near center
0	0	0	0
5	0.520	0.657	0.720
10	0.748	0.973	0.955
15	0.994	1.302	1.400
20	1.194	1.525	1.800
25	1.474	1.826	2.500
30	1.732	2.065	2.850
35	1.962	2.255	3.250
40	2.352	2.535	3.845
45	2.660	2.744	4.235
50	3.181	2.991	4.824
55	3.543	3.232	5.350
60	3.783	3.423	5.985
65	3.985	3.696	6.325
70	4.287	4.022	6.850
75	4.588	4.292	6.995
80	4.935	4.659	7.345
85	5.185	4.921	7.985
90	5.515	5.192	8.430
95	5.867	5.494	8.948
100	6.325	5.911	9.235
105	6.752	6.331	9.854
110	7.013	6.774	10.235
115	7.332	7.011	10.685
120	7.632	7.401	10.995

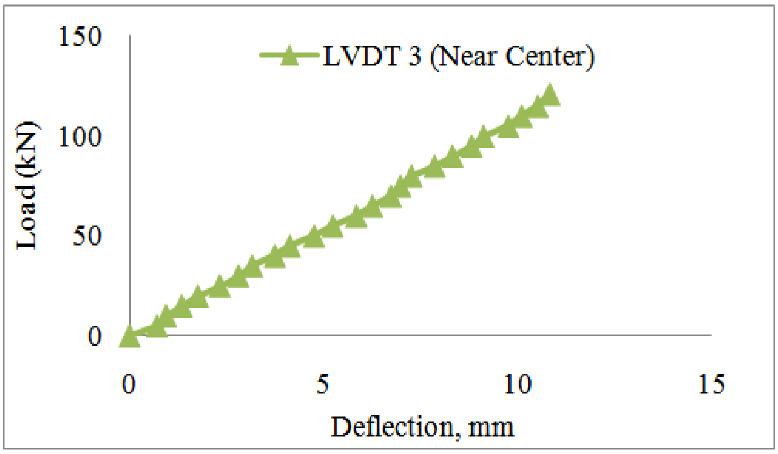

Figure 10 Approximate average load versus deflection
(Hybrid FRP – U WRAP)

3.3. Test Results and Discussions

The entire beam specimens were tested to their ultimate load carrying capacity and the test results of load-deflections of each beam specimen is noted. It is to be noted that the capacity of the control beams is around 80 Kn whereas the for the strengthened beams it is 120 kn. This shows an increase of 50% in the load carrying capacity of the strengthened beams The following cases were analyzed.

- Control RC beam
- Strengthened RC beam under flexure with U-shaped CFRP &GFRP with hybrid frp laminates (U pattern). The graph showing the comparison of the Ultimate load is depicted below.

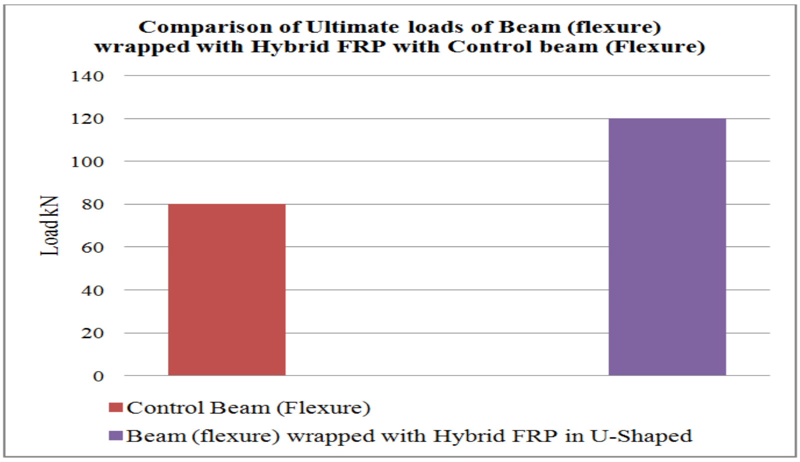

Figure 11 Comparison of Ultimate loads of Beam (flexure) wrapped with Hybrid FRP with Control beam (Flexure)

4. ANALYTICAL STUDY OF RC BEAMS WITH HYBRID STRENGTHENING

Modeling the RC beam has been done to examine the behaviour of beam. The components such as steel and concrete are done ideally and further defined together for simulation.

The geometry of the element is created with their own physical properties with a size of 100mm x 200mm x 1500mm.

Further the process of meshing is carried out maintaining the uniformity of seed size.

A model with the deformed shape and cracking pattern is depicted below.

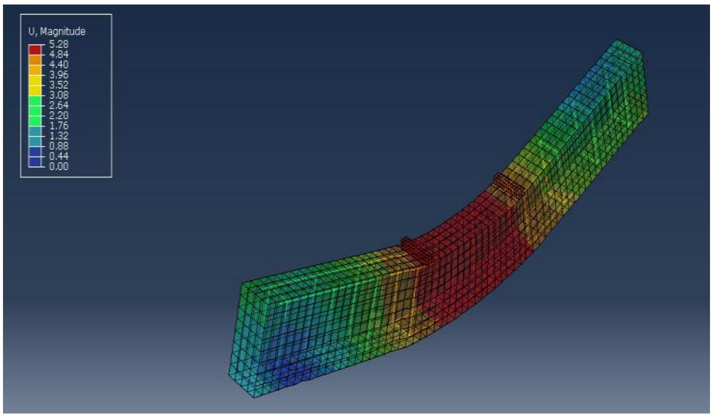

Figure 12 Deformed shape of the Beam – control

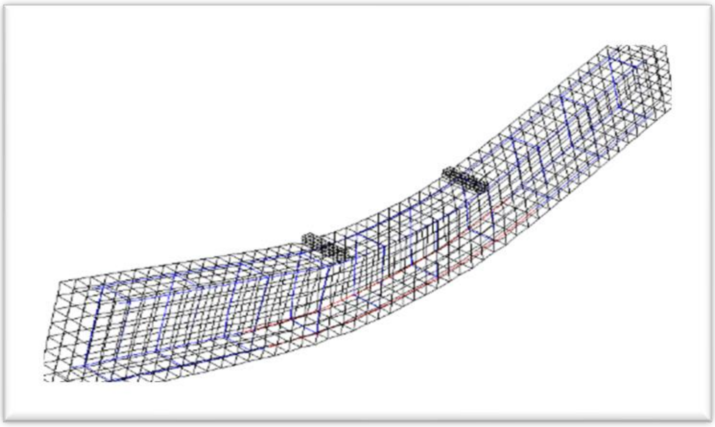

Figure 13 Cracking of concrete and yielding of steel

4.1. Test Results using Analytical Investigation

The maximum percentage difference between the predicted and the corresponding experimental observation is ±15%. For example, the predicted maximum load and the corresponding deflection for the control flexure beam are 75 kN and 8.08mm and the corresponding experimental observations are 82 kN and 7.40 mm. The presented Result confirm that the numerical simulation of the RC beam can simulate the behavior of experimental studies.

Comparison of load – deflection responses

Specimen	**Finite element analysis**		**Experimental**	
	Max Load (kN)	**Deflection, mm**	**Max Load (kN)**	**Deflection, mm**
Control Beam	75	8.08	82	7.40
Strengthened with U-shaped	116	10.36	120	10.99

4.2. Summary

It is observed that the responses obtained from FE analysis are in close agreement with the corresponding experimental Value indicating that the developed FE models are robust and reliable.

5. CONCLUSION

- The failure pattern of both control beams and strengthened beams show the same behavior of failure while testing to its ultimate load carrying capacity.
- The test results shows a greater advantage in double layer wrapping, since the properties of
- each parent material is different, to overcome the behavior Hybrid FRP (GFRP & CFRP) is the better solution.
- The specimens wrapped with hybrid in U pattern failed at an average maximum load of 120kN and the average maximum deflection is 10.846mm. In this pattern of wrapping, the strength has improved and the increase is 40kN than the control beams.
- The flexural behaviour of strengthened beam proven to be better than the control beams.

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